



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<b>(21) International Application Number:</b> PCT/CA96/00841 <b>(22) International Filing Date:</b> 12 December 1996 (12.12.96) <b>(30) Priority Data:</b> 2,165,041 12 December 1995 (12.12.95) CA <b>(60) Parent Application or Grant</b> (63) Related by Continuation US 08/571,175 (CIP) Filed on 12 December 1995 (12.12.95) <b>(71) Applicant (for all designated States except US):</b> THE UNIVERSITY OF BRITISH COLUMBIA [CA/CA]; IRC Room 331, 2194 Health Sciences Mall, Vancouver, British Columbia V6T 1Z3 (CA). <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> WITHERS, Stephen, G. [CA/CA]; University of British Columbia, Dept. of Chemistry, Vancouver, British Columbia V6T 1Z1 (CA). MACKENZIE, Lloyd [CA/CA]; University of British Columbia, Dept. of Chemistry, Vancouver, British Columbia V6T 1Z1 (CA). WANG, Quingping [CA/CA]; 95 Sedgefield Avenue, Pointe Claire, Quebec H9R 1N8 (CA).	<b>(74) Agents:</b> ROBINSON, Christopher, J. et al.; Smart & Biggar, Vancouver Centre, Box 11560, Suite 2200, 650 West Georgia Street, Vancouver, British Columbia V6B 4N8 (CA). <b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). <b>Published</b> <i>Without international search report and to be republished upon receipt of that report.</i>	
<b>(54) Title:</b> METHODS AND COMPOSITIONS FOR SYNTHESIS OF OLIGOSACCHARIDES USING MUTANT GLYCOSIDASE ENZYMES <b>(57) Abstract</b> <p>Mutant glycosidase enzymes are formed in which the normal nucleophilic amino acid within the active site has been changed to a non-nucleophilic amino acid. These enzymes cannot hydrolyze disaccharide products, but which can still form them. Using this enzyme, oligosaccharides are synthesized by preparing a mixture of an <math>\alpha</math>-glycosyl fluoride and a glycoside acceptor molecule; enzymatically coupling the <math>\alpha</math>-glycosyl fluoride to the glycoside acceptor molecule to form a glycosyl glycoside product using the mutant glycosidase enzyme; and recovering the glycosyl glycoside product. Particular enzymes include a mutant form of <i>Agrobacterium</i> <math>\beta</math>-Glucosidase in which the normal glutamic acid residue at position 358 is replaced with an alanine residue.</p>		

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METHODS AND COMPOSITIONS FOR SYNTHESIS OF OLIGOSACCHARIDES USING MUTANT  
GLYCOSIDASE ENZYMES

BACKGROUND OF THE INVENTION

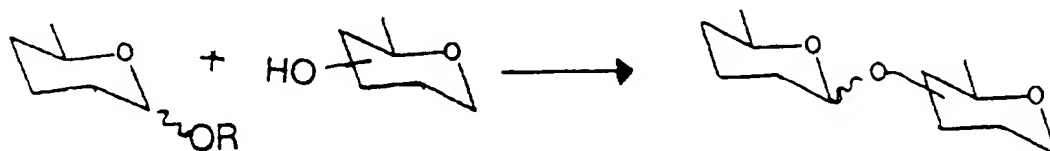
This application relates to methods and compositions for synthesizing oligosaccharides, and to the oligosaccharide products which can be obtained using such methods and compositions.

Oligosaccharide are compounds with considerable potential both as therapeutics and as reagents for clinical assays. The very nature of the saccharide subunits, however, makes the synthesis of many oligosaccharide of potential interest a daunting task because of the many possibilities for formation

of positional isomers in which different substituent groups on the sugars become involved in bond formation and potential for the formation of different anomeric forms. Because of these factors, chemical synthesis of most oligosaccharides while possible is not generally feasible on a commercial scale because of poor yields of the desired product.

An alternative to chemical synthesis of oligosaccharides is enzymatic synthesis. In particular, enzymatic synthesis using glycosyl transferases, glycosidases or combinations thereof has been considered as a possible approach to the synthesis of oligosaccharides.

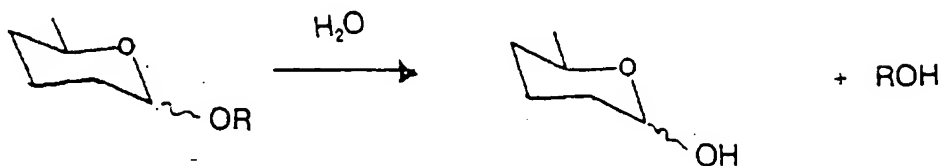
Glycosyl transferases catalyze the reaction



Glycosyl transferases can be very effective for producing specific products with good stereochemical and regiochemical control, if a transferase with the desired specificity is available. The enzymes can be expensive and hard to handle since they are often membrane-associated and unstable, however, and the required nucleotide sugar substrates can be quite expensive. Furthermore, glycosyl transferases possessing the desired

specificity to make many interesting oligosaccharides are not available.

Glycosidases catalyze the reaction



and synthesize oligosaccharides when the reaction is run in reverse from the normal direction. In addition, oligosaccharide synthesis can be achieved by adding a second sugar to the reaction mixture which competes with water and reacts in its place with the first sugar in a transglycosylation reaction. Glycosidases are generally available and easy to handle and have the potential to make many different products using inexpensive substrates. Unfortunately, it is difficult to control the reverse hydrolysis reaction which leads to poor product yields. In addition, while the stereochemical control (i.e., the formation of only one anomer) is generally good, it is hard to predict or control the regiochemistry (i.e., the formation of 1-2 vs 1-3 vs 1-4 vs 1-6 bonds).

To realize the potential of enzymatic oligosaccharide synthesis, there is therefore a need for a synthetic approach which avoids the drawbacks of the known techniques. It is an

object of this invention to provide such a technique which permits the synthesis of a wide variety of oligosaccharides in good yield, and to provide enzymes suitable for practicing these techniques.

#### SUMMARY OF THE INVENTION

These and other objects of the invention can be achieved through the use of mutant glycosidase enzymes, which cannot hydrolyze disaccharide products, but can still form them. Thus, a first aspect of the present invention is a method for forming an oligosaccharide. In this method a mixture of a glycosyl donor and a glycoside acceptor molecule is prepared. The glycosyl donor is selected from among molecules having substituents at the 1-position which are good leaving groups. The glycosyl donor is then enzymatically coupled to the glycoside acceptor molecule to form a glycosyl glycoside product using a mutant glycosidase enzyme in which one of two key amino acids has been changed, and the glycosyl glycoside product is recovered. In the case of a "retaining" glycosidase, the mutant enzyme is one in which the normal nucleophilic amino acid within the active site had been changed to a non-nucleophilic amino acid. In the case of an "invertig" glycosidase, the mutant enzyme is one in which the amino acid which normally functions as a base has been replaced by a non-ionizable amino acid. In both cases, the

glycosyl donor is selected to have the opposite anomeric configuration from the desired product.

A further aspect of the present invention is a mutant glycosidase enzyme of the retaining type, in which the normal nucleophilic amino acid within the active site has been changed to an amino acid other than glutamic acid or aspartic acid. One such enzyme is a mutant form of *Agrobacterium*  $\beta$ -Glucosidase in which the normal glutamic acid residue at position 358 is replaced with an alanine residue.

A further aspect of the present invention is a mutant glycosidase enzyme of the inverting type, in which the normal amino acid that functions as a base within the active site has been changed to a non-ionizable amino acid.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows the hydrolysis of a disaccharide within the active site of a normal glycosidase enzyme which retains stereochemical configuration during hydrolysis;

Fig. 2 shows the hydrolysis of a disaccharide within the active site of a normal glycosidase enzyme which inverts stereochemical configuration during hydrolysis; and

Fig. 3 shows the synthesis of a disaccharide within the active site of a mutant glycosidase within the scope of the present invention.

### DETAILED DESCRIPTION OF THE INVENTION

This invention relates to mutant forms of glycosidase enzymes. Glycosidase enzymes can be classified as being either "retainers" because they retain the stereochemistry of the bond being broken during hydrolysis, or "inverters" because they invert the stereochemistry of the bond being broken during hydrolysis.

Normal stereochemistry retaining enzymes have two carboxylic acid groups in the active site of the enzyme as shown generally in Fig. 1. One of these groups functions as an acid/base catalyst (labeled as group 1 in Fig 1) and the other as a nucleophile (group 2 in Fig. 1). The nucleophile group 2 forms a glycosyl-enzyme intermediate which is then cleaved by the acid/base catalyst group 1 to result in a hydrolyzed glycoside in which the stereochemistry has been maintained.

Normal stereochemistry inverting enzymes also have two carboxylic acid groups in the active site of the enzyme as shown generally in Fig. 2. In inverting enzymes, however, one of these groups functions as an acid catalyst (labeled as group 3 in Fig 2) and the other as a base catalyst (group 4 in Fig. 2). The acid catalyst group 3 protonates the hemiacetal-hydroxyl group of the glycosyl donor molecule, making it a good leaving group, at the same time that the base catalyst group 4 deprotonates a donor molecule (water or HOR) allowing it to replace the leaving hydroxyl group with inversion of stereochemistry.



The present invention provides mutant forms of both retaining and inverting enzymes in which one of the two carboxylic acid amino acids in the active site has been replaced with a different amino acid. Such mutations provide enzymes which do not catalyze the hydrolysis of oligosaccharides, but which nevertheless retain activity to synthesize oligosaccharides with good control over the stereochemistry and regiochemistry of reaction.

Enzymes to which the methodology of the present invention may be employed include, for example,  $\beta$ -Glucosidases,  $\beta$ -galactosidases,  $\beta$ -mannosidases,  $\beta$ -N-acetyl glucosaminidases,  $\beta$ -N-acetyl galactosaminidases,  $\beta$ -xylosidases,  $\beta$ -fucosidases, cellulases, xylanases, galactanases, mannanases, hemicellulases, amylases, glucoamylases,  $\alpha$ -glucosidases,  $\alpha$ -galactosidases,  $\alpha$ -mannosidases,  $\alpha$ -N-acetyl glucosaminidases,  $\alpha$ -N-acetyl galactosaminidases,  $\alpha$ -xylosidases,  $\alpha$ -fucosidases, neuraminidases/sialidases such as those from: *Agrobacterium* sp., *Bacillus* sp., *Caldocellum* sp., *Clostridium* sp., *Escherichia coli*, *Kluveromyces* sp., *Klebsiella* sp., *Lactobacillus* sp., *Aspergillus* sp., *Staphylococcus* sp., *Lactobacillus* sp., *Butyrovibrio* sp., *Ruminococcus* sp., *Sulfolobus* sp., *Schizophyllum* sp., *Trichoderma* sp., *Cellulomonas* sp., *Erwinia* sp., *Humicola* sp., *Pseudomonas* sp., *Thermoascus* sp., *Phaseolus* sp., *Persea* sp., *Fibrobacter* sp., *Phanaerochaete* sp., *Microbispora* sp., *Saccharomyces* sp., *Hordeum vulgare*, *Glycine max*, *Saccharomycopsis* sp., *Rhizopus* sp., *Nicotiana*, *Phaseolus*

sp., rat, mouse, rabbit, cow, pig, and human sources. Preferred enzymes in accordance with the invention are mutant forms of retaining glycosidase enzymes.

In the enzymes of the present invention, one of the two amino acid residues with the active carboxylic acid side chains is changed to a different amino acid which does not act as a nucleophile (in the case of a retaining enzyme) or as a base catalyst (in the case of an inverting enzyme). Thus, in general, the substitution will involve replacing the glutamic acid or aspartic acid residue of the wild-type enzyme with alanine, glycine, valine, leucine, isoleucine, serine, threonine, cysteine, methionine, asparagine, glutamine, histidine, proline, phenylalanine, or tyrosine. Preferably, the substituted amino acid will have a side chain of approximately equal or smaller size to the side chain of the wild-type amino acid residue to avoid significant changes to the size and shape of the active site. Enzymes mutated in this way are inactive with the normal substrates, and thus cannot hydrolyze oligosaccharide products. They can, however, catalyze the coupling of modified glycosyl donor molecules to modified acceptors, for example the coupling of an  $\alpha$ -glycosyl fluoride donor to a  $\beta$ -glycoside acceptor as shown in Fig. 3. This reaction proceeds with substantial yield because the reverse hydrolysis reaction does not occur, and with good stereochemical and regiochemical control.

The site for mutation in a retaining glycosidase may be identified after trapping of the glycosyl-enzyme intermediate in the active site using one of the following approaches. First, the intermediate may be trapped by rapid denaturation of the enzyme, or a mutant thereof, after incubation in the presence of a substrate. Alternatively, the intermediate may be trapped using a modified substrate which forms a relatively stable glycosyl-enzyme intermediate. Possible modified substrates which could be used include 2-deoxy-2-halo glycosyl derivatives, 2-deoxy-2,2-dihalo glycosyl derivatives, 5-halo glycosyl derivatives, cyclitol epoxides, epoxyalkyl glycosides, glycosyl methyl triazenes and other glycosyl derivatives bearing a reactive functional group at their anomeric center.

Once this intermediate has been trapped, the labeled enzyme is then cleaved into peptides by use of a protease or by specific chemical degradation, and the peptide bearing the sugar label then located in a chromatogram or other separation method and its amino acid sequence determined. Comparison of this sequence with that of the intact enzyme readily identifies the amino acid of interest.

Identification of the labeled peptide may be achieved by a number of methods. These could include use of a radio-labeled glycosyl derivative, then searching for the radiolabeled peptide(s); comparative peptide mapping by HPLC or by LC/MS;

LC/MS-MS analysis of the peptides, monitoring in neutral loss mode for the loss of the sugar in the collision cell.

The catalytic nucleophile may also be identified in the three-dimensional structure of the enzyme determined by X-ray crystallography or NMR spectroscopy by inspection of the active site region, searching for a Glu or Asp residue. This would be facilitated by the inclusion of a substrate or an analogue in the active site of the enzyme.

Alternatively, the catalytic nucleophile may be identified by the generation of mutants in which each Glu and Asp residue which is shown to be highly conserved within a homologous (or analogous) family of enzymes has been replaced, individually, by Ala. Identification of the mutant which is capable of utilizing the "wrong" glycosyl fluoride as a substrate will thereby allow identification of the residue of interest.

The site for mutation in an inverting glycosidase may be identified by inspection of the three dimensional structure, where available, or by mutation of each glutamic acid and aspartic acid residue which is conserved within a sequence-related family to alanine and assaying each mutant for its ability to synthesize oligosaccharides using the corresponding glycosyl fluoride (i.e. a  $\beta$ -glycosyl fluoride for an  $\alpha$ -glycosidase mutant or an  $\alpha$ -glycosyl fluoride for a  $\beta$ -glycosidase mutant).

Using these procedures, we have determined the appropriate site for mutation for several glucosidase enzymes.

Thus, in *Agrobacterium*  $\beta$ -glucosidase, the mutant enzyme of the invention is prepared by replacing the glutamic acid at position 358 with another amino acid, for example alanine. Mutant  $\alpha$ -amylase (human or porcine) in accordance with the invention has the aspartic acid at position 197 replaced with another amino acid, for example alanine, while in yeast  $\alpha$ -glucosidase the aspartic acid at position 216 is replaced.

Once the site for mutation has been identified, a mutant gene is prepared using site directed mutagenesis to arrive at the desired result. In general, this involves the construction of a plasmid containing the coding sequence for the wild-type gene, and isolation of single stranded DNA. Copies are then made of the isolated plasmid DNA using a template dependant DNA polymerase and a primer which overlaps the site of the desired mutation and which differs from the wild-type sequence in the manner necessary to yield the desired mutation. The mutated plasmid is then transformed into a host organism, e.g., *E. coli*. Transformants are initially selected using a marker contained within the plasmid, and then further selected by sequencing of the expressed glycosidase enzyme to confirm the nature of the mutation.

Mutant enzymes according to the invention may be purified from the growth medium of the host organism by column chromatography, for example on DEAE-cellulose if desired. High levels of purity are not required for use in catalyzing

oligosaccharide synthesis, however, provided that impurities with wild-type glycosidase activity must be substantially absent.

The enzymes of the invention are used to couple  $\alpha$ -modified glycosyl donors with glycoside acceptor. Preferred donor molecules are glycosyl fluorides, although other groups which are reasonably small and which function as relatively good leaving groups can also be used. Examples of other glycosyl donor molecules include glycosyl chlorides, acetates, propionates, and pivaloates, and glycosyl molecules modified with substituted phenols. The donor molecules may be monosaccharides, or may themselves contain multiple sugar moieties.

Glycosyl fluorides can be prepared from the free sugar by first acetylating the sugar and then treating it with HF/pyridine. This will generate the thermodynamically most stable anomer of the protected (acetylated) glycosyl fluoride. If the less stable anomer is desired, it may be prepared by converting the peracetylated sugar with HBr/HOAc or with HCl to generate the anomeric bromide or chloride. This intermediate is reacted with a fluoride salt such as silver fluoride to generate the glycosyl fluoride. Acetylated glycosyl fluorides may be deprotected by reaction with mild (catalytic) base in methanol (e.g., NaOMe/MeOH). In addition, glycosyl donor molecules, including many glycosyl fluorides can be purchased commercially. Thus a wide range of donor molecules are available for use in the methods of the present invention.

The glycoside acceptor used in the method of the present invention may be essentially any glycoside molecule containing from 1 to 10 sugar moieties. The acceptor molecule may be substituted at positions away from the group which is coupled by the enzyme. Thus, the glycoside acceptor may be a monosaccharide, an oligosaccharide, or a sugar-containing molecule, such as an aminoglycoside antibiotic.

When the donor molecule is an  $\alpha$ -glycosyl donor molecule, the glycoside acceptor used is a  $\beta$ -glycoside acceptor, and vice versa. The acceptor and donor are combined in an aqueous buffer (for example 250 mM sodium phosphate buffer, pH 7.0 or 250 mM ammonium carbonate buffer, pH 7.75) in a mole ratio (acceptor/donor) of about 1 to 2.5, more preferably 1.1 to 2.0 together with a catalytic amount (i.e., about 0.02 to 0.5 mg/ml) of mutant enzyme and incubated at around 25 °C for a period of time sufficient to produce significant yields of product, for example 12 hours to 4 days.

To remove the buffer from the product when phosphate buffer is used, the reaction mixture is combined with 5 volumes of methanol, filtered through a silica plug (5 cm) and concentrated in vacuo. For carbonate buffer, the mixture is co-evaporated with water (3 times) in vacuo. The residues from either procedure are then dissolved in acetonitrile/methanol, filtered and purified by silica gel chromatography or HPLC. The

purified product can then be dissolved in water and freeze-dried or crystallized to yield a solid product.

On a commercial scale, it may be advantageous to immobilize the enzyme to facilitate its removal from a batch of product and subsequent reuse. Such immobilization could be accomplished by use of a fusion protein in which the mutant glycoside is engineered onto another protein with high affinity for an insoluble matrix. For example, a fusion protein with a cellulose binding protein prepared in the manner described by Ong et al., "Enzyme Immobilization Using the Cellulose-Binding Domain of a *Cellulomonas fimi* Exoglucanase", *Biotechnology* 7: 604-607 (1989) could be used in accordance with the invention.

The method of the invention can be used to make a wide variety of oligosaccharides. Particularly useful oligosaccharides which can be made by this method include cello-oligosaccharides and cello-oligosaccharide glycans which are very difficult to synthesize chemically but which are of interest because of their use in the study of cellulases, and oligosaccharide-based inactivators of cellulases which can be used to study cellulase activity and which have potential as antifungal agents, particularly in the control of wood-degrading fungi. Another application of the present invention is the synthesis of malto-oligosaccharide derivatives with a  $\beta$ -linked sugar (glucose, galactose, mannose, fructose, N-acetylglucosamine) attached at



the non-reducing end. Such products would be useful in clinical assays for  $\alpha$ -amylase.

#### EXAMPLE 1

*Escherichia coli* strains JM101 (Viera & Messing, 1988) and RZ1032 (Kunkel et al., 1987) have been described. Plasmid pTZ18Rabg was constructed by taking the coding sequence of the  $\beta$ -glucosidase gene (abg) from pABG5 (Wakarchuk et al., 1986) and inserting it into pTZ18R. JM101 was maintained on M9 minimal media. Plasmid containing strains were grown in Luria broth containing 100 ug/mL ampicillin.

Single-stranded DNA was isolated by the following method. Cultures were grown on TYP (16g/L tryptone, 16g/L yeast extract, 5g/L NaCl, 2.5g/L K<sub>2</sub>HPO<sub>4</sub>) medium containing 100ug/mL ampicillin and 10<sup>9</sup> PFU/mL helper phage M13K07 (Viera and Messing, 1988). Kanamycin (50 ug/mL) was added 1 h after inoculation, and the culture was grown 6-10 h at 37°C. Phagemid were precipitated with 1.7 M ammonia acetate and 12% (w/v) PEG-6000. Single-stranded DNA was isolated from the phagemid by method of Kristensen et al (Kristensen et al., 1987). Uracil-containing template was generated by growing the plasmid in strain RZ1032. Site-directed mutants were generated by the method of Kunkel (Kunkel, 1987) with modifications for phagemid vectors. The specific mutation of the active site nucleophile (E358) were carried out with the oligonucleotide primer:

TACATCACCG CAAACGGCGC CTGC

SEQ ID NO.: 1

T7 DNA polymerase was used for the extension reactions. After in vitro mutagenesis, the plasmid DNA (pTUG10NAbgE358A) was transformed into JM101. Transformants were selected on LB agar containing 2% 5-bromo-4-chloro-3-indolyl- $\beta$ -D-glucopyranoside, 1mM isopropyl- $\beta$ -D-thiogalactopyranoside and 100 ug/mL ampicillin. Possible mutants were screened by single-track sequencing and confirmed by complete sequencing reactions. The entire coding region of *Agrobacterium*  $\beta$ -glucosidase was then sequenced to confirm that only the desired mutations was present. DNA sequencing was performed by the method of Tabor and Richardson (Tabor & Richardson (1987), *Proc. Natl. Acad. Sci. U.S.A.* 84, 4767). Expression level of the mutant protein was monitored by SDS-PAGE followed by Western blot analysis with wild type enzyme as a control. Kristensen, T., Voss, H., & Ansorge, W. (1987) *Nucleic Acids Res.* 15, 5507. Kunkel, T. A., Roberts, J. D., & Zakour, R. A. (1987) *Methods Enzymol.* 154, 367. Tabor, S. & Richardson, C. C. (1987). Viera, J. & Messing, J. (1988) *Gene* 19, 259. Wakarchuk, W. W., Kilburn, D. G., Miller, R. C., Jr., & Warren, R. A. J. (1986) *Mol. Gen. Genet.* 205, 146.

*Agrobacterium* E358A- $\beta$ -Glucosidase was purified by modification of the method employed for isolation of the native enzyme from *E. coli*. Kempton & Withers, (1992) *Biochemistry*, 31, 9961, except that enzyme presence and activity was measured with

2,4-dinitrophenyl- $\beta$ -D-glucoside with sodium azide (Wang et al., (1994) *J. Amer. Chem. Soc.*, 116, 11594.

Protein was expressed in *E. coli* JM101 from the lac promotor of pTZ18R. Cells grown overnight in 200 mL of Typ Amp media at 30°C were used to inoculate the fermentor (15-20 L) at a level of 0.5-1.0%. The cells were grown to 2-3OD<sub>600</sub>, treated with 0.1 mM IPTG and harvested when growth reached 6-7OD<sub>600</sub>.

Cells were harvested by Sharples continuous centrifugation at 31 000 x g and the cell paste stored at -20°C. The cell pellet from the 15 L culture was thawed at 25°C and resuspended in 1-2 mL of 50 mM sodium phosphate, 2 mM EDTA buffer, pH 7.0, per gram of cell paste. The mixture was then passed twice through a French pressure cell and cell debris removed by centrifugation (20 000 x g for 30 min.). Steptomycin sulphate was added to this extract to a concentration of 1.5% (w/v). The mixture was stirred for 4 hr. at 4°C and then centrifuged (20 000 x g for 30 min.) to remove the precipitated nucleic acids. The extract was then loaded onto a DEAE-Sephacel column (45 cm x 5 cm) equilibrated with 50 mM sodium phosphate 2 mM EDTA buffer, pH 7.0. The column was eluted with 2 x 1 L linear gradient of 0.1 M sodium chloride in starting buffer. Fractions containing the highest activity of E358A  $\beta$ -glucosidase were pooled, dialyzed overnight against 50 mM sodium phosphate buffer, pH 7.0 and concentrated using Amicon Centiprep 30 centrifuge ultrafiltration devices.

Silver stained SDS-PAGE showed the single column purification of E358A  $\beta$ -glucosidase to be approximately 95% homogenous. Protein concentration was determined using the absorbance value of  $E_{280,0.1\%} = 2.184 \text{ cm}^{-1}$ . The mass of the E358A mutant was confirmed to be 58 amu's lower than that of the wild-type enzyme by electrospray mass spectrometry. Protein was used without any further purification for transglycosylation experiments.

#### EXAMPLE 2

$\alpha$ -Galactosyl fluoride (0.35 mmoles) and p-nitrophenyl- $\beta$ -D-glucoside (0.22 mmoles) were dissolved in 3.0 ml of 250 mM ammonium carbonate buffer (pH 7.75). 25  $\mu$ l of an 8.75 mg/ml stock solution of E358A  $\beta$ -glucosidase was added. After incubation at 25°C for 48 hours, TLC analysis (Merck Kieselgel 60 F-254 plates, solvent system 7:2:1 ethyl acetate, methanol, water) indicated the reaction had gone to completion. Buffer was removed from the reaction system by transferring to a round bottom flask and co-evaporating with water (3X 25 ml) in vacuo. The residue was dissolved in acetonitrile/methanol (10:1), filtered and purified by silica gel chromatography. The resulting oil was dissolved in water and freeze dried to yield 85 grams (84% yield) of an amorphous solid.

The amorphous solid was analyzed by  $^1\text{H}$  NMR, Mass Spectroscopy and elemental analysis. The product was identified as p-nitrophenyl-4-O-(glucopyranosyl)- $\beta$ -D-galactopyranoside.

EXAMPLE 3

$\alpha$ -Glucosyl fluoride was coupled to a variety of aryl-glucoside acceptors using E-358A  $\beta$ -glucosidase. Reactions were run at a donor to acceptor mole ratio of 1.1 - 1.3 in ammonium carbonate buffer (pH 7.7) for a period of 48 hours. The products were recovered and purified by silica gel chromatography or HPLC, and analyzed by  $^1\text{H}$  NMR and Mass Spectroscopy. The results are summarized in Table 1. As can be seen, the two main products in all cases were the  $\beta$ -1,4 linked cellobioside and cellotrioside, both of which were formed in substantial yields. These products all have potential utility as cellulase inhibitors and substrates.

This example was repeated by using additional aryl-glycoside acceptors at a donor to an acceptor mole ratio of 1.1-2.1 and the results are summarized in Table 1(a).

**Table 1.** Transglycosylation Reactions of *Agrobacterium*  $\beta$ -Glucosidase E358A Mutant with  $\alpha$ -Glucosyl Fluoride (Donor) and Aryl-Glucosides (Acceptors).

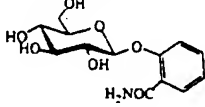
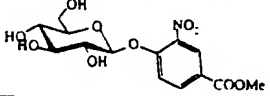
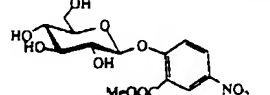
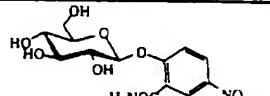
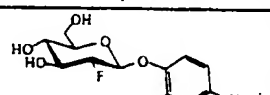
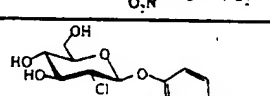
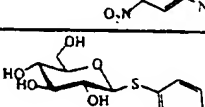
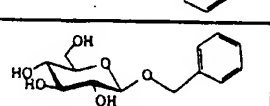
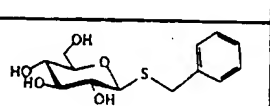
#	ACCEPTOR	PRODUCTS (% YIELD)			
		$\beta$ -1,4 linked			Total Yield†
		Cellobioside	Cellotrioside	Cellotetraoside	
1		48%	34%	-	82%
2		38%	24%	10%	72%
3		41%	29%	6%	76%
4		34%	29%	7%	70%
5		44%	24%	-	58%
6		37%	36%	-	73%

† Yields are based on isolated products.

Reactions were set up with 1.1-1.3 equivalents of  $\alpha$ -glucosyl fluoride relative to the acceptor.

Typical reaction performed on 25-50 mg of acceptor and larger scale reactions from 100mg -1000mg.

Table 1. Continued.

#	ACCEPTOR	PRODUCTS (% YIELD)			
		$\beta$ -1,4 linked			Total Yield†
		Cellobioside	Cellotrioside	Cellotetraoside	
7		54%	22%	-	76%
8		22%	46%	-	68%
9		26%	34%	6%	66%
10		42%	34%	3%	79%
11		38%	42%	4%	84%
12		42%	40%	4%	86%
13		34%	22%	-	56%
14		22%	37%	-	59%
15		12%	24%	-	36%

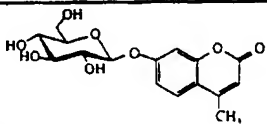
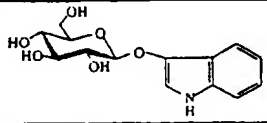
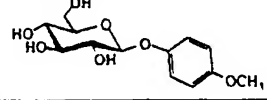
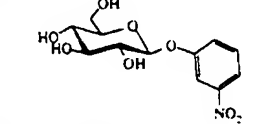
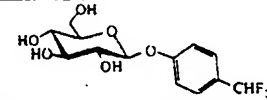
† Yields based on isolated products.

Reactions were set up with 1.1-1.3 equivalents of  $\alpha$ -glucosyl fluoride relative to the acceptor.

Typical reaction performed on 25-50 mg of acceptor and larger scale reactions from 100mg - 1000mg.

Table 1(a)

Additional Examples of Transglycosylation Reactions of *Agrobacterium*  $\beta$ -Glucosidase E358A Mutant with  $\alpha$ -Glucosyl Fluoride (Donor) and Aryl-Glycosides (Acceptors).

#	ACCEPTOR	PRODUCTS (% YIELD)			
		$\beta$ -1,4 linked			Total Yield†
		Cellobioside	Cellotrioside	Cellotetraoside	
1		-	84%	6%	90%
2		28%	50%	-	78%
3		50%	16%	-	66%
4		37%	34%	-	71%
5		48%	21%	-	69%

† Yields are based on isolated products.

Reactions were set up with 1.1-2.1 equivalents of  $\alpha$ -glucosyl fluoride relative to the acceptor.

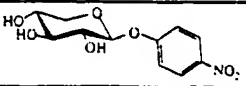
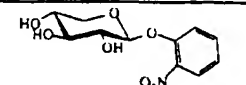
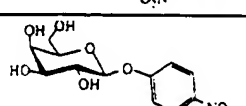
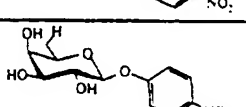
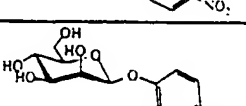
Typical reaction performed on 5-50 mg of acceptor and larger scale reactions from 100mg - 1000mg.



**EXAMPLE 4**

To evaluate the effect of the donor molecule on the products formed, the experiment of Example 3 was repeated using different aryl-glycosides as donors. The results of this experiment are shown in Table 2. As can be seen, selection of the nature of the donor moiety in some cases shifts the reaction to the production of  $\beta$ -1,3 linkages, but in each case still produced a good yield of product.

**Table 2.** Transglycosylation Reactions of *Agrobacterium*  $\beta$ -Glucosidase E358A Mutant with  $\alpha$ -Glucosyl Fluoride (Donor) and Aryl-Glycosides (Acceptors).

#	ACCEPTOR	PRODUCTS (% YIELD)			
		$\beta$ -1,4 linked (or if * $\beta$ -1,3 linked to acceptor)			Total Yield†
		Disaccharide	Trisaccharide	Tetrasaccharide	
1		12%*	51%*	3%	66%
2		14%*	44%*	4%	62%
3		6%*	8%*	-	14%
4		18%*	36%*	-	54%
5		31%	42%	6%	79%

† Yields based on isolated products. \* -Product linkage type not yet determined.

Reactions were set up with 1.1-1.3 equivalents of  $\alpha$ -glucosyl fluoride relative to the acceptor.

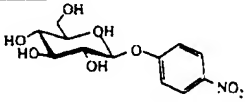
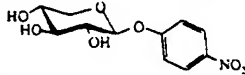
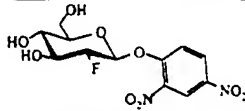
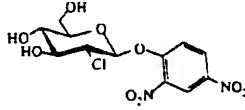
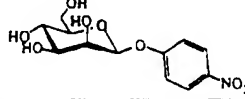
Typical reaction performed on 25-50 mg of acceptor and larger scale reactions from 100mg -1000mg.

EXAMPLE 5

Transglycosylation reactions according to the invention were performed to couple  $\alpha$ -galactosyl fluoride with various aryl-glycosides. Reactions were run at a donor to acceptor mole ratio of 1.5 - 2.0 in ammonium carbonate buffer (pH 7.7) for a period of 48 hours. The products were recovered and purified by silica gel chromatography or HPLC, and analyzed by  $^1\text{H}$  NMR and mass spectroscopy. The results are summarized in Table 3. In each case, a good yield of a disaccharide product was obtained. In each case for which the product linkage has been determined, the linkage type was  $\beta$ -1,4.

This example was repeated using additional aryl-glycoside acceptors with a donor acceptor mole ratio of 1.5-2.0 with 5-50 or 100-1,000 mg of acceptor. The results are shown in Table 3(a).

**Table 3.** Transglycosylation Reactions of *Agrobacterium*  $\beta$ -Glucosidase E358A Mutant with  $\alpha$ -Galactosyl Fluoride (Donor) and Aryl-Glycosides (Acceptors).

#	ACCEPTOR	PRODUCTS (% YIELD)	
		$\beta$ -1,4 linked(unless otherwise stated)	
		Disaccharide	Total Yield†
1		84%	84%
2		81%*	81%
3		54%	54%
4		64%	64%
5		66%*	66%

† Yields based on isolated products. \* -Product linkage type not yet determined.

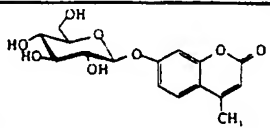
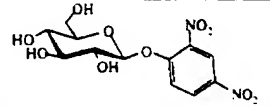
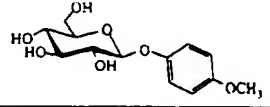
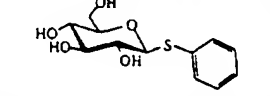
Reactions were set up with 1.5-2.0 equivalents of  $\alpha$ -galactosyl fluoride relative to the acceptor.

Typical reaction performed on 25-50 mg of acceptor and larger scale reactions from 100mg -1000mg.

Note: Galactose as a donor acts as a chain terminator under these conditions, so only dissaccharides are produced.

Table 3(a)

Additional Examples of Transglycosylation Reactions of *Agrobacterium*  $\beta$ -Glucosidase E358A Mutant with  $\alpha$ -Galactosyl Fluoride (Donor) and Aryl-Glycosides (Acceptors).

#	ACCEPTOR	PRODUCTS (% YIELD)	
		$\beta$ -1,4 linked	
		Disaccharide	Total Yield†
1		79%	79%
2		68%	68%
3		75%	75%
4		72%	72%

† Yields based on isolated products.

Reactions were set up with 1.5-2.0 equivalents of  $\alpha$ -galactosyl fluoride relative to the acceptor.

Typical reaction performed on 5-50 mg of acceptor and larger scale reactions from 100mg -1000mg.

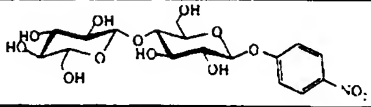
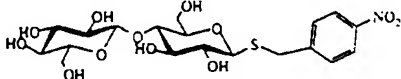
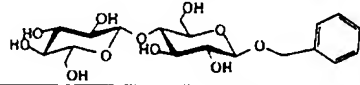
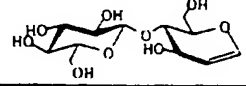
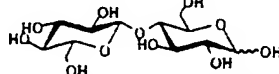
Note: Galactose as a donor acts as a chain terminator under these conditions, so only disaccharides are produced.

#### EXAMPLE 6

Transglycosylation reactions according to the invention were performed to couple  $\alpha$ -glucosyl fluoride with various cellobiosyl derivatives. Reactions were run at a donor to

acceptor mole ratio of 1.1 - 1.4 in phosphate buffer (pH 7.0) for a period of 24 hours. The products were recovered and purified by silica gel chromatography or HPLC, and analyzed by  $^1\text{H}$  NMR and mass spectroscopy. The results are summarized in Table 4. In each case, good yield of  $\beta$ -1,4-linked trisaccharide and tetrasaccharide products were obtained.

**Table 4.** Transglycosylation Reactions of *Agrobacterium*  $\beta$ -Glucosidase E358A Mutant with  $\alpha$ -Glucosyl Fluoride (Donor) and Cellobiosyl Derivatives (Acceptors).

#	ACCEPTOR	PRODUCTS (% YIELD)		
		$\beta$ -1,4 linked		Total Yield <sup>†</sup>
		Trisaccharide	Tetrasaccharide	
1		79%	13%	92%
2		64%	21%	85%
3		71%	15%	86%
4		31%	28%	59%
5		22%	21%	43%

<sup>†</sup> Yields based on isolated products. Reactions were set up with 1.1-1.4 equivalents of  $\alpha$ -glucosyl fluoride relative to the acceptor.

Typical reaction performed on 25-50 mg of acceptor and larger scale reactions from 100mg -1000mg.

EXAMPLE 7

A transglycosylation reaction according to the invention was performed to couple  $\alpha$ -galactosyl fluoride with p-nitrophenyl- $\alpha$ -D-maltoside. Reactions were run at a donor to acceptor mole ratio of 1.1 - 1.4 in ammonium carbonate buffer (pH 7.7) for a period of 48 hours. The products were recovered and purified by HPLC, and analyzed by  $^1\text{H}$  NMR and mass spectroscopy. p-Nitrophenyl-4'-O- $[\beta$ -D-galactopyranosyl]- $\alpha$ -D-maltoside was recovered in 64% yield.

EXAMPLE 8

Identification of the nucleophile of *Agrobacterium faecalis*  $\beta$ -glucosidase was performed by trapping the intermediate formed between the enzyme and 2',4'-dinitrophenyl 2-deoxy-2-fluoro- $\beta$ -D-glucoside (2F-DNPG).

Synthesis of 2',4'-dinitrophenyl 2-deoxy-2-fluoro- $\beta$ -D-glucoside has been reported previously (Withers, S. G., Warren, R. A. J., Street, I. P., Rupitz, K., Kempton, J. B. & Aebersold, R. (1990) *J. Amer. Chem. Soc.* 112, 5887-5889). Briefly this involved treatment of 1,3,4,6-tetra-O-acetyl 2-deoxy-2-fluoro-D-glucose (Adam. M. (1982) *J. Chem. Soc. Chem. Commun.* 730-731) with 1.1 equivs of hydrazine acetate in dimethyl formamide and heating for 3 minutes. This was then cooled to room temperature, and reaction monitored until complete as determined by TLC. The

resultant hemiacetal was then dissolved in dimethyl formamide (1 g in 10 mL) containing 4A molecular sieves and DABCO (0.15 g) and 1-fluoro-2,4-dinitrobenzene added. The reaction mixture was stirred at room temperature for 1.5 hours, then the sieves were removed by filtration and the solvent evaporated *in vacuo* to yield an oil which was dissolved in chloroform and washed successively with a saturated solution of sodium bicarbonate, then water, and dried over MgSO<sub>4</sub>. The solvent was evaporated *in vacuo* to give an oil which solidified on trituration with ethanol. The product was then recrystallized from ethanol to yield the per-O-acetylated glycoside. This product was deprotected by suspending a sample of the glycoside (70 mg) in dry methanol (15 mL) and adding acetyl chloride (1 mL). This reaction mixture was stirred for 24 h at 4 °C, then solvent removed by evaporation *in vacuo*, and the product crystallized from ethanol.

A sample of  $\beta$ -glucosidase (400  $\mu$ g, 7.8 mg/mL) was inactivated with 2F-DNPG (0.32 mM) in 50 mM sodium phosphate buffer, pH 6.8 at 37 °C by incubation for 5 minutes. The labeled enzyme was then completely digested using 1:100 pepsin (w/w; enzyme:substrate) in 50 mM sodium phosphate buffer, pH 2.0, at room temperature. The proteolytic digest (10  $\mu$ g) was loaded onto a C18 column (Reliasil, 1 x 150 mm), then eluted with a gradient of 0-60% solvent B over 20 minutes followed by 100% B for 2 minutes at a flow rate of 50  $\mu$ l/minute.

The intact enzyme, unlabeled and labeled with 2F-DNPG, and the eluted materials from the C18 column were evaluated by mass spectrometry. Mass spectra were recorded on a PE-Sciex API III triple quadrupole mass spectrometer (Sciex, Thornhill, Ont., Canada) equipped with an ionspray ion source. Protein or peptide samples were separated by reverse phase HPLC on an Ultrafast Microprotein Analyzer (Michrom BioResources Inc., Pleasanton, CA) directly interfaced with the mass spectrometer, using solvent A: 0.05% trifluoroacetic acid, 2% acetonitrile in water and solvent B: 0.045% trifluoroacetic acid, 80% acetonitrile in water. A post-column flow splitter was used to introduce 15% of the HPLC eluate into the mass spectrometer, while 85% was collected for further analysis.

Intact protein samples (10 µg, native or labeled) were introduced into the mass spectrometer through a microbore PLRP column (1 X 50 mm) on the Michrom HPLC system (solvent system: 20-100% solvent B over 10 minutes, 100% solvent B over 2 minutes). The quadrupole mass analyzer (in the single quadrupole mode) was scanned over a  $m/z$  range 300-2400 Da with a step size of 0.5 Da and a dwell time of 1 ms per step. The ion source voltage (ISV) was set at 5 kV and the orifice energy (OR) was 80 V. Protein molecular weights were determined from this data using the deconvolution software supplied by Sciex.

The single quadrupole mode (normal LC/MS) MS conditions used were identical to those for analysis of the intact protein.



The neutral loss MS/MS spectra were obtained in the triple quadrupole neutral loss scan mode searching for the mass loss corresponding to the loss of the label from a peptide ion in the singly or doubly charged state. Thus, scan range:  $m/z$  300-1200; step size: 0.5 Da; dwell time: 1 ms per step; ISV: 5 kV; OR: 80; RE1 = 115; DM1 = 0.16; R1 = 0 V; R2 = -50 V; RE3 = 115; DM3 = 0.16; Collision gas thickness (CGT):  $3.2 - 3.6 \times 10^{14}$  molecules/cm<sup>2</sup>. (CGT = 320-360). To maximize the sensitivity of neutral loss detection, normally the resolution is compromised without generating artifact neutral loss peaks.

Peptic proteolysis of 2FGlu-labeled Abg resulted in a mixture of peptides which was separated by reverse phase-HPLC, using the ESIMS as a detector. When the spectrometer was scanned in the normal LC-MS mode, the total ion chromatogram (TIC) of the 2FGlu-Abg digest displayed a large number of peaks, reflecting the complexity of the mixture. The 2FGlu-labeled peptide was then identified in a second run using the tandem mass spectrometer set up in the neutral loss scanning mode (MS/MS). In this mode, the ions are subjected to limited fragmentation by collisions with argon in a collision cell. The ester linkage between the 2FGlu label and the peptide is one of the more labile linkages present, readily susceptible to homolytic cleavage. Indeed, the collision conditions employed were sufficient to break the ester bond but not generally the peptide bonds. This results in the loss of a neutral 2FGlumoiety, leaving the peptide moiety with its original

charge. The two quadrupoles are then scanned in a linked manner such that only ions differing in  $m/z$  by the mass corresponding to the label can pass through both quadrupoles and be detected. In some cases, however, it may be necessary to scan for  $m/z$  differences of one half or one third the mass of the neutral species as the peptide may be doubly or triply charged.

When the spectrometer was scanned in the neutral loss MS/MS mode, searching for a mass loss corresponding to the 2FGlu moiety of  $m/z$  165, two peaks were observed in the total ion chromatogram which are not seen in an equivalent chromatogram of a peptic hydrolysate of unlabeled Abg, suggesting that this was the peptide of interest.

The identity of this peptide can be easily probed by calculation of its mass. The labeled peptide observed of  $m/z$  871 corresponds to an unlabeled peptide 706 Da while that at  $m/z$  1035 corresponds to a peptide of mass 870 Da. A search of the amino acid sequence of Abg for all possible peptides of mass 730 Da and 870 Da containing the same Glu or Asp residue produced a short list of candidates from which the true sequence was determined by MS/MS analysis.

#### EXAMPLE 9

A fusion protein combining the E358A mutant of *Agrobacterium*  $\beta$ -glucosidase and the cellulose-binding domain of *Cellulomonas fimi* was prepared using the general approach of Ong

et al., *supra*. Plasmid pTUG10NAbgE358A (encoding AbgE358A) and plasmid pEO1 (encoding Abg-CBDcex) were each cut with Avr II and Sph I. The 0.78 kb fragment liberated from pTUG10NAbgE358A carrying the mutation was isolated by GeneClean as was the 4.2 Kb fragment from pEO1. The two fragments were ligated together (T4 DNA ligase) effectively replacing the corresponding wild-type fragment in pEO1 with the mutation. The ligation mixture was transformed to electrocompetent *E. coli* DH5 $\alpha$ F'. Ampicillin resistant clones were selected and the plasmid DNA isolated by the Quiagen method. This yielded pAMC (encoding AbgE358A-CBDcex). The mutation was confirmed by sequencing and mass spectroscopy.

The plasmid was transformed to electrocompetent *E. coli* TB-1 for expression of the recombinant protein. To prepare the fusion protein, the host organism is grown under inducing conditions. Cells are harvested by centrifugation, washed and broken in a French press. PMSF and pepstatin are immediately added to inhibit proteolysis after which cellular debris is removed by centrifugation. Fusion protein is then purified by cellulose affinity chromatography on Whatman CF1 cellulose, followed by elution and concentrated by ultrafiltration. The purified fusion protein may be immobilized on a cellulose matrix for use in oligosaccharide synthesis. The presence of the mutant E358A can be confirmed by reaction with dinitrophenyl- $\beta$ -D-glucoside in the presence of sodium azide and/or by SDS-PAGE.

## SEQUENCE LISTING

- (1) GENERAL INFORMATION:
- (i) APPLICANT: Withers, Stephen G.  
MacKenzie, Lloyd  
Wang, Qingping
  - (ii) TITLE OF INVENTION: METHODS AND COMPOSITIONS FOR SYNTHESIS OF OLIGOSACCHARIDES AND THE PRODUCTS FORMED THEREBY
  - (iii) NUMBER OF SEQUENCES: 1
  - (iv) CORRESPONDENCE ADDRESS:
    - (A) ADDRESSEE: OPPEDAHN & LARSON
    - (B) STREET: 1992 Commerce Street Suite 309
    - (C) CITY: Yorktown Heights
    - (D) STATE: NY
    - (E) COUNTRY: US
    - (F) ZIP: 10598
  - (v) COMPUTER READABLE FORM:
    - (A) MEDIUM TYPE: Diskette - 3.50 inch, 1.44 Mb storage
    - (B) COMPUTER: IBM Compatible
    - (C) OPERATING SYSTEM: MS DOS 6
    - (D) SOFTWARE: Word Perfect 6.1
  - (vi) CURRENT APPLICATION DATA :
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    - (C) CLASSIFICATION:
  - (vii) PRIOR APPLICATION DATA:
    - (A) APPLICATION NUMBER:
    - (B) FILING DATE:
  - (viii) ATTORNEY/AGENT INFORMATION :
    - (A) NAME: Larson, Marina T.
    - (B) REGISTRATION NUMBER: 32,038
    - (C) REFERENCE/DOCKET NUMBER: UBC.P-005-US
  - (ix) TELECOMMUNICATION INFORMATION:
    - (A) TELEPHONE: (914)245-3252
    - (B) TELEFAX: (914) 962-4330
    - (C) TELEX:
- (2) INFORMATION FOR SEQ ID NO: 1:
- (i) SEQUENCE CHARACTERISTICS:
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    - (B) TYPE: nucleic acid
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  - (iv) ANTI-SENSE: no
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    - (A) NAME/KEY:

- (B) LOCATION:  
(C) IDENTIFICATION METHOD:  
(D) OTHER INFORMATION: primer for site directed mutagenesis to  
produce E358A mutant of Agrobacterium beta-glucosidase  
(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

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24

We Claim:

1. A method for synthesizing an oligosaccharide comprising the steps of:
  - (a) combining a glycosyl donor molecule and a glycoside acceptor molecule in a reaction mixture; and
  - (b) enzymatically coupling the donor molecule to the acceptor molecule using a mutant form of glycosidase enzyme to form the oligosaccharide, said enzyme being selected from among glycosidase enzymes having two catalytically active amino acids with carboxylic acid side chains within the active site of the wild-type enzyme, and said mutant enzyme being mutated to replace one of said amino acids having a carboxylic acid side chain with a different amino acid of comparable or smaller size, said different amino acid having a non-carboxylic acid side chain.
2. The method of claim 1, wherein the glycosidase enzyme is a stereochemistry retaining enzyme in which one of the carboxylic acid side chains in the active site functions as an acid/base catalyst and the other carboxylic acid side chain functions as a nucleophile, and wherein the amino acid having the nucleophilic carboxylic acid side chain is replaced in the mutant enzyme.
3. The method of claim 2, wherein the enzyme is a  $\beta$ -glycosidase.

4. The method of claim 3, wherein the glycosyl donor molecule is an  $\alpha$ -glycosyl fluoride.

5. The method of claim 4, wherein the  $\alpha$ -glycosyl fluoride is an  $\alpha$ -glucosyl fluoride.

6. The method of claim 4, wherein the  $\alpha$ -glycosyl fluoride is an  $\alpha$ -galactosyl fluoride.

7. The method of claim 1, wherein the enzyme is a  $\beta$ -glycosidase.

8. The method of claim 1, wherein the enzyme is a  $\beta$ -glucosidase.

9. The method of claim 8, wherein the enzyme is *Agrobacterium*  $\beta$ -glucosidase in which amino acid 358 has been changed from glutamic acid to an amino acid with a non-carboxylic acid side chain.

10. The method of claim 8, wherein the enzyme is *Agrobacterium*  $\beta$ -glucosidase in which amino acid 358 has been changed from glutamic acid to alanine.

11. The method of claim 1, wherein the acceptor molecule is an aryl-glycoside.

12. The method of claim 11, wherein the acceptor molecule is a nitrophenyl-glycoside.

13. The method of claim 1, wherein the glycosidase enzyme is a stereochemistry inverting enzyme in which one of the carboxylic acid side chains in the active site functions as an acid catalyst and the other carboxylic acid side chain functions as a base catalyst, and wherein the amino acid having the carboxylic acid side chain which functions as a base catalyst is replaced in the mutant enzyme.

14. The method of claim 1, wherein the enzyme is a mutant form of human or porcine  $\alpha$ -amylase in which amino acid 197 has been changed from aspartic acid to alanine.

15. The method of claim 1, wherein the enzyme is a mutant form of human or porcine  $\alpha$ -amylase in which amino acid 197 has been changed from aspartic acid to an amino acid with a non-carboxylic acid side chain.



16. The method of claim 1, wherein the enzyme is a mutant form of yeast  $\alpha$ -glucosidase in which amino acid 216 has been changed from aspartic acid to alanine.

17. The method of claim 1, wherein the enzyme is a mutant form of yeast  $\alpha$ -glucosidase in which amino acid 216 has been changed from aspartic acid to a non-carboxylic acid amino acid.

18. A mutant form of a glycosidase enzyme, said enzyme being selected from among glycosidase enzymes having two catalytically active amino acids with carboxylic acid side chains within the active site of the wild-type enzyme, one of said carboxylic acid side chains functioning as a nucleophile and one of said carboxylic acid side chains functioning as an acid/base catalyst, and said mutant form of the enzyme being mutated to replace the amino acid having the nucleophilic carboxylic acid side chain with an amino acid having a non-nucleophilic side chain of comparable or smaller size.

19. The mutant enzyme of claim 18, wherein the nucleophilic carboxylic acid is the side chain of a glutamic acid residue in the wild-type enzyme, and wherein said glutamic acid is replaced with an alanine residue in the mutant.

20. The mutant enzyme of claim 18, wherein the enzyme is a  $\beta$ -glucosidase.

21. The mutant enzyme of claim 20, wherein the enzyme is *Agrobacterium*  $\beta$ -glucosidase in which amino acid 358 has been changed from glutamic acid to alanine.

22. A mutant form of a glycosidase enzyme, said enzyme being selected from among glycosidase enzymes having two catalytically active amino acids with carboxylic acid side chains within the active site of the wild-type enzyme, one of said carboxylic acid side chains functioning as a base catalyst and one of said carboxylic acid side chains functioning as an acid catalyst, and said mutant form of the enzyme being mutated to replace the amino acid residue having the carboxylic acid side chain functioning as a base catalyst with an amino acid having a non-ionizable side chain of comparable or smaller size.

23. A mutant form of human or porcine  $\alpha$ -amylase in which the aspartic acid at position 197 is replaced with a different amino acid having a non-carboxylic acid side chain such that the enzyme cannot catalyze the hydrolysis of oligosaccharides.

24. The mutant amylase of claim 23, wherein the different amino acid is alanine.

25. A mutant form of yeast  $\alpha$ -glucosidase in which the aspartic acid at position 216 is replaced with a different amino acid having a non-carboxylic acid side chain such that the enzyme cannot catalyze the hydrolysis of oligosaccharides.

26. The mutant  $\alpha$ -glucosidase of claim 25, wherein the different amino acid is alanine.

27. An oligosaccharide prepared by the steps of

(a) combining a glycosyl donor molecule and a glycoside acceptor molecule in a reaction mixture; and

(b) enzymatically coupling the donor molecule to the acceptor molecule using a mutant glycosidase enzyme to form the oligosaccharide, said enzyme being selected from among glycosidase enzymes having two catalytically active amino acids with carboxylic acid side chains within the active site of the wild-type enzyme, and said mutant enzyme being mutated to replace one of the amino acid residues having a catalytically active carboxylic acid side chain as a side chain with an amino acid having a non-carboxylic acid side chain.

28. The oligosaccharide of claim 27, wherein the glycosidase enzyme is a stereochemistry retaining enzyme in which one of the carboxylic acid side chains in the active site functions as an acid/base catalyst and the other carboxylic acid side chain functions as a nucleophile, and wherein the amino acid having the nucleophilic carboxylic acid side chain is replaced in the mutant enzyme of comparable of smaller size.

29. The oligosaccharide of claim 28, wherein the enzyme is a  $\beta$ -glycosidase.

30. The oligosaccharide of claim 29, wherein the glycosyl donor molecule is an  $\alpha$ -glycosyl fluoride.

31. The oligosaccharide of claim 30, wherein the  $\alpha$ -glycosyl fluoride is an  $\alpha$ -glucosyl fluoride.

32. The oligosaccharide of claim 30, wherein the  $\alpha$ -glycosyl fluoride is an  $\alpha$ -galactosyl fluoride.

33. The oligosaccharide of claim 29, wherein the enzyme is a  $\beta$ -glucosidase.

34. The oligosaccharide of claim 28, wherein the enzyme is *Agrobacterium*  $\beta$ -glucosidase in which amino acid 358 has been changed from glutamic acid to alanine.

35. The oligosaccharide of claim 28, wherein the acceptor molecule is an aryl-glycoside.

36. The oligosaccharide of claim 35, wherein the acceptor molecule is a nitrophenyl-glycoside.

37. A fusion protein comprising

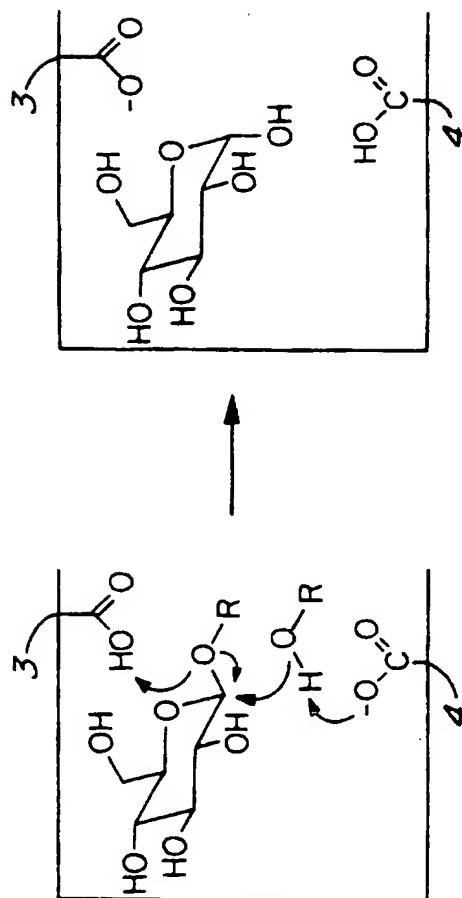
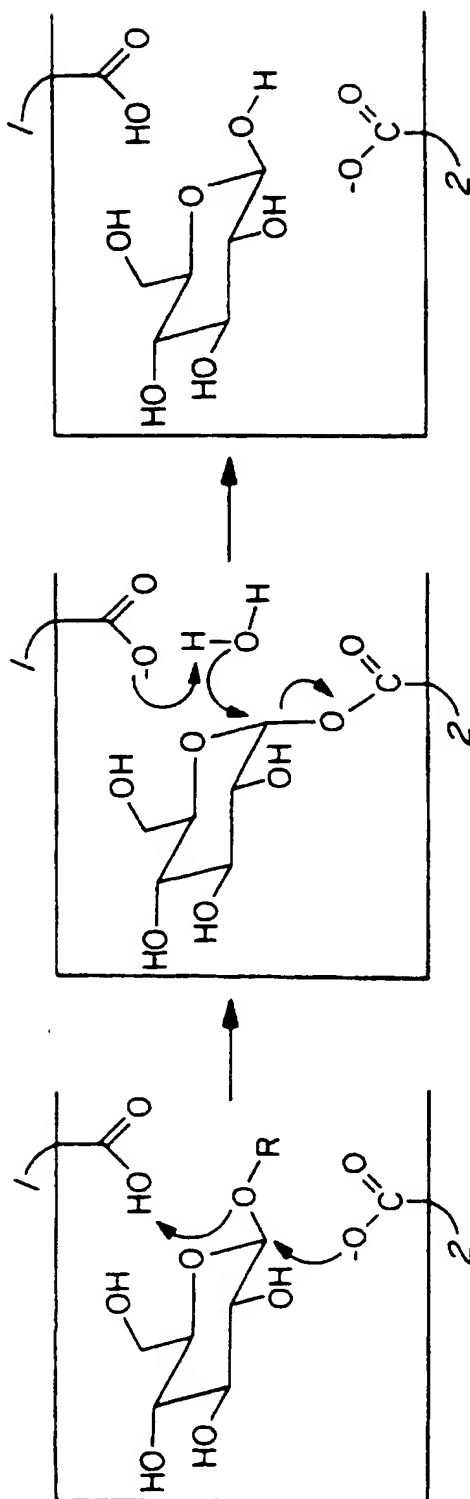
(a) an enzymatically active mutant form of a glycosidase enzyme, said enzyme being selected from among glycosidase enzymes having two catalytically active amino acids with carboxylic acid side chains within the active site of the wild-type enzyme, and said mutant form of the enzyme being mutated to replace one of the amino acids having a catalytically active carboxylic acid side chain with an amino acid having a non-carboxylic acid side chain of comparable or smaller size; and

(b) a binding protein having high affinity for an insoluble matrix.

38. The fusion protein of claim 37, wherein the binding protein is cellulose binding protein.

39. The fusion protein of claim 38, wherein the glycosidase is a  $\beta$ -glycosidase.

1/2



2/2

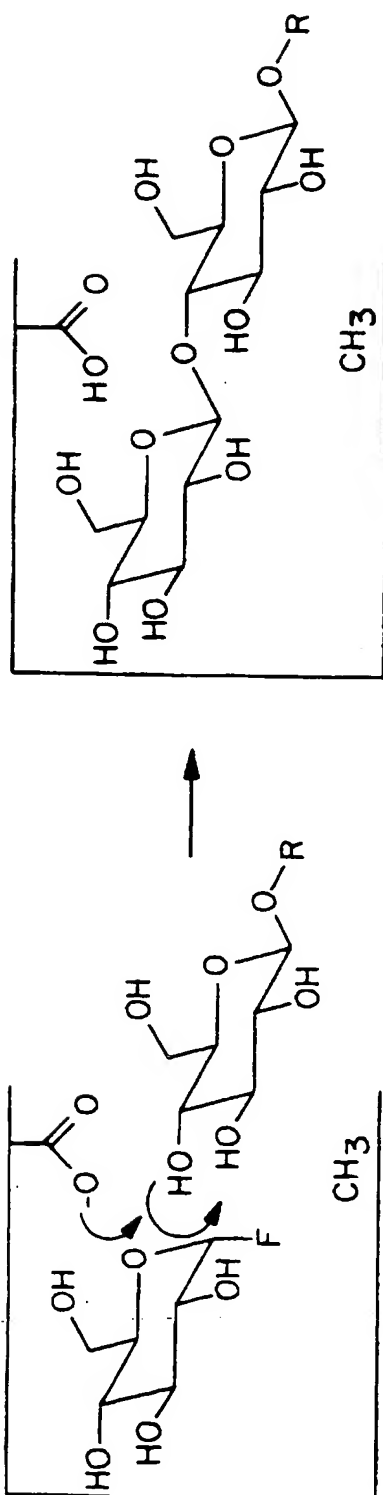


FIG. 3





## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>6</sup> :</b> C12N 15/52, C12P 19/04, C12N 9/24, 9/26, 15/62	<b>A3</b>	<b>(11) International Publication Number:</b> WO 97/21822 <b>(43) International Publication Date:</b> 19 June 1997 (19.06.97)
<b>(21) International Application Number:</b> PCT/CA96/00841 <b>(22) International Filing Date:</b> 12 December 1996 (12.12.96)  <b>(30) Priority Data:</b> 2,165,041 12 December 1995 (12.12.95) CA  <b>(60) Parent Application or Grant</b> (63) Related by Continuation US 08/571,175 (CIP) Filed on 12 December 1995 (12.12.95)  <b>(71) Applicant (for all designated States except US):</b> THE UNIVERSITY OF BRITISH COLUMBIA [CA/CA]; IRC Room 331, 2194 Health Sciences Mall, Vancouver, British Columbia V6T 1Z3 (CA).  <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> WITHERS, Stephen, G. [CA/CA]; University of British Columbia, Dept. of Chemistry, Vancouver, British Columbia V6T 1Z1 (CA). MACKENZIE, Lloyd [CA/CA]; University of British Columbia, Dept. of Chemistry, Vancouver, British Columbia V6T 1Z1 (CA). WANG, Quingping [CA/CA]; 95 Sedgefield Avenue, Pointe Claire, Quebec H9R 1N8 (CA).	<b>(74) Agents:</b> ROBINSON, Christopher, J. et al.; Smart & Biggar, Vancouver Centre, Box 11560, Suite 2200, 650 West Georgia Street, Vancouver, British Columbia V6B 4N8 (CA).  <b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>  <b>(88) Date of publication of the international search report:</b> 28 August 1997 (28.08.97)	
<b>(54) Title:</b> METHODS AND COMPOSITIONS FOR SYNTHESIS OF OLIGOSACCHARIDES USING MUTANT GLYCOSIDASE ENZYMES		
<b>(57) Abstract</b>  Mutant glycosidase enzymes are formed in which the normal nucleophilic amino acid within the active site has been changed to a non-nucleophilic amino acid. These enzymes cannot hydrolyze disaccharide products, but which can still form them. Using this enzyme, oligosaccharides are synthesized by preparing a mixture of an $\alpha$ -glycosyl fluoride and a glycoside acceptor molecule; enzymatically coupling the $\alpha$ -glycosyl fluoride to the glycoside acceptor molecule to form a glycosyl glycoside product using the mutant glycosidase enzyme; and recovering the glycosyl glycoside product. Particular enzymes include a mutant form of <i>Agrobacterium</i> $\beta$ -Glucosidase in which the normal glutamic acid residue at position 358 is replaced with an alanine residue.		

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# INTERNATIONAL SEARCH REPORT

International Application No.  
PCT/CA 96/00841

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC 6 C12N15/52 C12P19/04 C12N9/24 C12N9/26 C12N15/62		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) IPC 6 C12P C12N		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used)		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 89 09275 A (NILSSON KURT G I) 5 October 1989	1-13
X	see the whole document ---	27-33
Y	WO 87 05936 A (JOHANSSON HANNA MARIA E; HEDBYS LARS OLOF; LARSSON PER OLOF; MOSBACH KL) 8 October 1987	1-13
X	see the whole document ---	27-33
Y	EP 0 226 563 A (SVENSKA SOCKERFABRIKS AB) 24 June 1987	1-13
X	see the whole document ---	27-33
-/--		
<div style="display: flex; justify-content: space-between;"> <span><input checked="" type="checkbox"/> Further documents are listed in the continuation of box C.</span> <span><input checked="" type="checkbox"/> Patent family members are listed in annex.</span> </div>		
* Special categories of cited documents : <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>*A* document defining the general state of the art which is not considered to be of particular relevance</p> <p>*E* earlier document but published on or after the international filing date</p> <p>*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>*O* document referring to an oral disclosure, use, exhibition or other means</p> <p>*P* document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>*&amp;* document member of the same patent family</p> </div> </div>		
Date of the actual completion of the international search  <div style="text-align: center; font-size: 1.2em;">17 April 1997</div>		Date of mailing of the international search report  <div style="text-align: center; font-size: 1.2em;">15.07.97</div>
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016		Authorized officer  <div style="text-align: center; font-size: 1.2em;">Hix, R</div>

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# INTERNATIONAL SEARCH REPORT

International Application No.

PCT/CA 96/00841

## C. (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	J. AM. CHEM. SOC. (1994), 116(25), 11594-5 CODEN: JACSAT; ISSN: 0002-7863, 1994, XP000645301 WANG, QINGPING ET AL: "Changing Enzymic Reaction Mechanisms by Mutagenesis: Conversion of a Retaining Glucosidase to an Inverting Enzyme"	18-21
Y	see the whole document	1-13, 37-39
X	--- BIOCHEMISTRY 31 (41). 1992. 9979-9985. CODEN: BICHAW ISSN: 0006-2960, XP000645263 WITHERS S G ET AL: "MECHANISTIC CONSEQUENCES OF MUTATION OF THE ACTIVE SITE NUCLEOPHILE GLU 358 IN AGROBACTERIUM BETA GLUCOSIDASE."	18
Y	see the whole document	1-13, 37-39
X	--- ACS SYMP. SER. (1992), 533(.BETA.-GLUCOSIDASES), 42-55 CODEN: ACSMC8; ISSN: 0097-6156, 1992. XP000618969 TRIMBUR, D. ET AL: "A beta- glucosidase from an Agrobacterium sp.: structure and biochemistry"	18
Y	see the whole document	1-13, 37-39
X	--- BIOCHEMISTRY 34 (44). 1995. 14547-14553. ISSN: 0006-2960, XP000645333 GEBLER J C ET AL: "Substrate-induced inactivation of a crippled beta- glucosidase mutant: Identification of the labeled amino acid and mutagenic analysis of its role."	18
	see the whole document	
A	--- BIOCHEMISTRY 34 (44). 1995. 14554-14562. ISSN: 0006-2960, XP000645264 WANG Q ET AL: "Identification of the acid-base catalyst in Agrobacterium faecalis beta- glucosidase by kinetic analysis of mutants."	
	see the whole document	
A	--- J. AM. CHEM. SOC. (1995), 117(40), 10137-8 CODEN: JACSAT; ISSN: 0002-7863, 1995, XP000645302 WANG, QINGPING ET AL: "Substrate-assisted catalysis in glycosidases"	
	see the whole document	
	---	

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# INTERNATIONAL SEARCH REPORT

Application No.

PC/CA 96/00841

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>PROTEIN ENGINEERING 6 (8). 1993. 913-920.  ISSN: 0269-2139, XP000645268  WITT E ET AL:  "6-Phospho-beta-galactosidases of  Gram-positive and 6-phospho-beta-  glucosidase B of Gram-negative bacteria:  Comparison of structure and function by  kinetic and immunological methods and  mutagenesis of the lacG gene of  Staphylococcus aureus."  see the whole document</p>	
P,X	<p>ANNALS OF THE NEW YORK ACADEMY OF  SCIENCES,  vol. 799, 1996,  pages 19-25, XP000618968  P.V. NIKOLOVA ET AL.: "Transglycosylation  by wild type and mutants of a  beta-1,4-glycosidase from Cellulomonas  fimi (Cex) for synthesis of  oligosaccharides."  see the whole document</p>	<p>1-13,  18-21,  27-39</p>

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# INTERNATIONAL SEARCH REPORT

1 national application No.

PCT/CA 96/00841

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see continuation-sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort incurring an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

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Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

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## INTERNATIONAL SEARCH REPORT

International Application No. PCT/CA 96/ 00841

FURTHER INFORMATION CONTINUED FROM PCT/SA/210

- 1.) Claims 1, 2, 11 to 13, 18, 27, 28, 35 to 38 (partially) and Claims 3 to 10, 19 to 21, 29 to 34 and 39 (completely): A method for synthesizing oligosaccharides comprising using a **mutant Agrobacterium  $\beta$ -glucosidase**, the mutant  $\beta$ -glucosidase enzyme, oligosaccharides produced by said process and fusion proteins comprising the mutant  $\beta$ -glucosidase enzyme.
- 2.) Claims 1, 2, 11 to 13, 18, 22, 27, 28, 35 to 38 (partially) and Claims 14, 15, 23 and 24 (completely): A method for synthesizing oligosaccharides comprising using a **mutant human or porcine  $\alpha$ -amylase**, the mutant  $\alpha$ -amylase enzyme, oligosaccharides produced by said process and fusion proteins comprising the mutant  $\alpha$ -amylase enzyme.
- 3.) Claims 1, 2, 11 to 13, 18, 22, 27, 28, 35 to 38 (partially) and Claims 16, 17, 25 and 26 (completely): A method for synthesizing oligosaccharides comprising using a **mutant yeast  $\alpha$ -glucosidase**, the mutant yeast  $\alpha$ -glucosidase enzyme, oligosaccharides produced by said process and fusion proteins comprising the mutant yeast  $\alpha$ -glucosidase enzyme.

# INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

PCT/CA 96/00841

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 8909275 A	05-10-89	SE 466403 B	10-02-92
		DE 68923177 D	27-07-95
		DE 68923177 T	15-02-96
		EP 0432157 A	19-06-91
		SE 8801080 A	25-09-89
		US 5246840 A	21-09-93
-----			
WO 8705936 A	08-10-87	SE 452776 B	14-12-87
		EP 0410963 A	06-02-91
		JP 63502900 T	27-10-88
		SE 8601482 A	03-10-87
-----			
EP 0226563 A	24-06-87	SE 451849 B	02-11-87
		JP 62240695 A	21-10-87
		SE 8505842 A	12-06-87
		US 4918009 A	17-04-90
-----			

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